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# Investigation of Corrosion on Inland Petroleum Distribution System Aluminum Pipe Grooved Ends Caused by Rubber Gaskets

by Howard E. Horner

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## **Investigation of Corrosion on Inland Petroleum Distribution System Aluminum Pipe Grooved Ends Caused by Rubber Gaskets**

**Howard E. Horner**

Weapons and Materials Research Directorate, ARL

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## Abstract

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Because of fuel leaks at a number of mechanically connected joints, the Inland Petroleum Distribution System (IPDS) unit at Fort Lee, VA, was disassembled. Corrosion had occurred on the bare surfaces of the aluminum pipe single-grooved ends in the connection joints. These corroded surfaces were in contact with the rubber gaskets inside the IPDS joint couplings. An investigation was performed to determine the cause of the corrosion. The joint gasket was made of epichlorohydrin rubber material, which contains a high chlorine content. Some chlorine, in the form of ions, combined with water or moisture trapped in the joint gaps to form hydrochloric acid to corrode the aluminum. Therefore, the primary cause of corrosion on the bare aluminum surfaces was the improper use of epichlorohydrin rubber material for the gaskets inside the joint couplings. A simple accelerated corrosion test procedure was established to verify the mode of corrosion on the bare aluminum surfaces. Samples of the original IPDS rubber gaskets were taken, and new sample gaskets made of two different rubber materials (i.e., reformulated epichlorohydrin and nitrile) were evaluated on bare aluminum surfaces.

## ACKNOWLEDGMENTS

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## 1. INTRODUCTION

Corrosion was observed on the bare metal surfaces at the grooved ends of the painted aluminum pipes in the Inland Petroleum Distribution System (IPDS) unit after it was disassembled at Fort Lee, VA, because of the fuel leaks that were observed at a number of mechanically connected joints. When assembled, long sections of the 6-in inside-diameter pipe were joined together at their grooved ends by IPDS snap-joint couplings containing the split integral rubber gaskets for sealing. The keys of the coupling housing halves were engaged into the single groove around both pipe ends, securing the ends together. Meanwhile, upon clamping, the split rubber gasket halves inside the coupling were compressed around the bare metal at both grooved ends to form the seal against fluid leakage at the joint connection.

After the IPDS was assembled at the field, water was used initially during the hydrostatic pressure test to check for leaks at the joint connections. Two days later, the water was then flushed out of the system with a low air pressure; however, some water may remain trapped in the gaps at the coupled joints. Diesel fuel was used in the IPDS during the training exercises by the troops in the field. The system was in use for about 10% of the time. After 8 or 9 months in the field and after the fuel leaks were observed at a number of connected joints, the IPDS unit was disassembled to determine the cause of leakages. Corroded areas were observed on the bared surfaces (unpainted areas) of the pipe grooved ends, which were in contact with the rubber gaskets inside the couplings clamped on the pipe ends, hence, the reason for the investigation of the corrosion problem in the IPDS.

Incidentally, the IPDS was designed for short-time use in the field under battlefield conditions, usually 90 days or less. Petroleum fuel, such as diesel fuel or jet fuel, is to be used in the IPDS in the field. Water is used only for hydrostatic pressure test purposes for a brief period to check for fluid leaks at the joint connections after the IPDS is assembled.

When epichlorohydrin rubber was mentioned as the material used for the gaskets in the IPDS, the probable cause of the corrosion was immediately apparent. This rubber material contains a

high chlorine content, some of which, as ions, will combine with water or moisture to form hydrochloric acid, which, in turn, will corrode aluminum. Epichlorohydrin rubber was used because of its superior service for petroleum fuels at low temperatures.

A simple accelerated corrosion test procedure was established and performed to verify the mode of corrosion on bare aluminum by the original IPDS gasket rubber material and to quickly evaluate two new gasket samples made of two different rubber materials (i.e., reformulated epichlorohydrin and nitrile) as to their corrosive effects on bare aluminum.

The information used in this report was extracted from two memorandums with attached reports on the results of the IPDS corrosion problem and the corrosion tests on the rubber gasket samples on aluminum.

The corrosion investigation was done for the Fuel and Water Handling Team of the Mobility Technology Center-Belvoir (AMSTA-RBWH), U.S. Army Tank-automotive and Armaments Command, Fort Belvoir, VA, which has the technical responsibility for the IPDS.

1.1 Samples. Six short aluminum pipe sections with the corroded grooved end and nine rubber gasket halves from the disassembled IPDS unit at Fort Lee were received as samples for the corrosion investigation. In addition, two new one-piece rubber gaskets, made of two different rubber materials, were received as samples for the accelerated corrosion tests.

1.2 Test Methods. Visual examination and x-ray chemical analysis were performed on the corrosion products. The properties of the rubber material samples from the IPDS gaskets were determined by standard test procedures. The accelerated corrosion test procedure established and used in this work is described in more detail in section 2.

## 2. RESULTS

Visual examination was performed on the IPDS pipe and gasket samples. The short, corroded grooved end sections were cut from the 6-in inside-diameter aluminum alloy 6061-T6 single-grooved end pipes with 3/8-in wall thickness. A single groove, 1/2 in wide and 1/8 in deep, was already machined around the pipe about 1 in in from the end. In addition, the 1-in wide end was already machined for roundness. This machined surface was masked off when the pipe and the groove at both ends were painted at the manufacturing plant, thus leaving the machined surface bare. This was where the corrosion took place when the bare surface was in contact with the rubber gasket inside the IDPS snap-joint coupling at the joint connection. Although whitish corrosion products were present on the corroded bare aluminum surfaces, the extent of corrosion was superficial with a few small and shallow surface pittings. Figure 1 shows a typical example of the corroded area observed on the bare machined surface at the grooved end of a corroded aluminum pipe grooved end sample.

The C-shaped gasket sample halves were a part of the split integral rubber gasket consisting of two identical halves with each half inside one housing half of the IPDS snap-joint ferrous coupling. Each gasket half has a seal lip at each outside edge, which, when compressed, is in contact with the bare machined aluminum surface at the pipe grooved end when the coupling is clamped in place at the joint connection. The corrosion products were still on the seal lips of the gasket samples. Whitish corrosion products were on both seal lips of several gasket samples, indicating the connection of two aluminum pipe grooved ends. Other gasket samples have whitish corrosion products on one seal lip and red-brown rust corrosion products on the other lip, indicating connection of the aluminum grooved end pipe to the grooved end of a gate valve. Figure 2 shows typical examples of the corrosion products on the seal lips of two rubber gasket sample halves. Volume buildup of the whitish corrosion products may have affected the sealing of the gaskets against the fluid leaks at several joint connections.



Figure 1. View of the corroded area on the bare machined surface at the corroded IPDS aluminum pipe single-grooved end (actual size). The extent of corrosion was superficial with a few small and shallow surface pittings. Note the paint in the groove as compared to no paint on the machined surface.

As mentioned in section 1, chlorine in the epichlorohydrin rubber gasket material was the probable culprit in the corrosion of the aluminum pipe grooved ends. Samples of the corrosion products were scraped carefully from the corroded areas of the corroded pipe grooved end samples and the surfaces of gasket seal lips to check for chlorine by x-ray fluorescence analysis. Also, a rubber sample was obtained from a sample gasket half for x-ray analysis. An x-ray wavelength dispersive spectrometer was used for analysis.

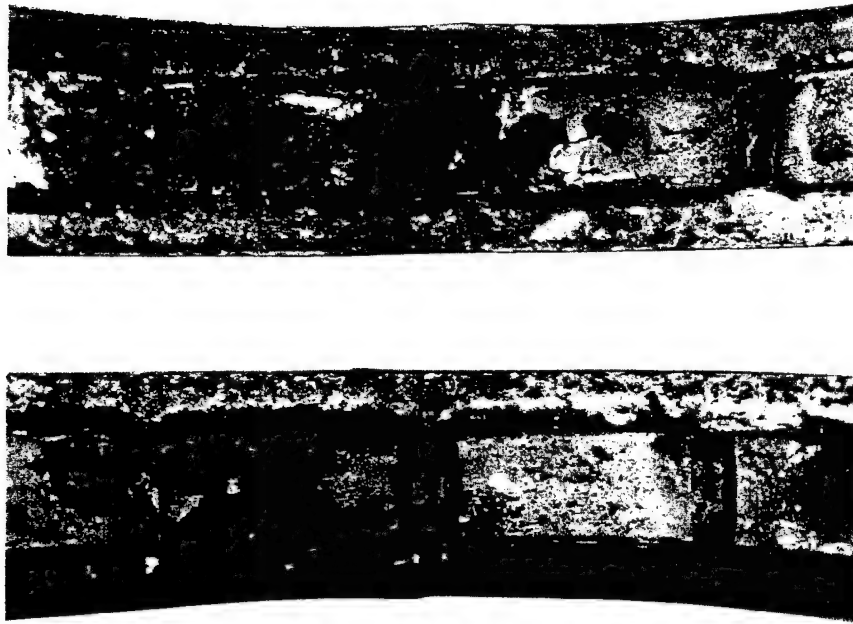


Figure 2. View of the IPDS integral split rubber gasket samples, showing the amount of the whitish corrosion products retained on the gasket seal lips on the outer edges (smaller than actual size).

Significant amounts of chlorine and lead were detected in the rubber sample. According to the technical literature on epichlorohydrin rubber, a lead compound, such as red lead (lead oxide) or lead phosphite, is used as a curing agent in the vulcanization of the rubber material. Phosphorous was not detected in the sample, indicating that red lead was probably used in the rubber formulation for the IPDS coupling gaskets. The presence of chlorine and lead strongly indicated the material of the IPDS coupling gasket as epichlorohydrin rubber.

Significant amounts of chlorine as well as some lead were detected in the whitish corrosion samples that were scraped from the corroded pipe ends, thus verifying the assumption that chlorine played a part in the corrosion of aluminum. Chlorine, as ions, combined with moisture or water to form hydrochloric acid, which, in turn, corroded the bare aluminum surface in contact with the rubber gasket. The acid was probably produced inside and outside the pipe at the

coupled joint, resulting from condensation or rain on the outside and moisture and water trapped inside in the joint gap. Similar comments also can be made on the whitish corrosion products that were slightly scraped from the seal lips of the gasket samples. Iron, chlorine, and some lead were detected in the red-rust corrosion products. In addition, the rust products were strongly attracted by a magnet, indicating that it was primarily magnetic iron oxide (Fe<sub>3</sub>O<sub>4</sub>) as the result of the ferrous valve grooved end rusting under the wet condition in contact with the rubber gasket.

A number of mechanical tests were performed on the IPDS rubber gasket sample. The results of the tests are given in Table 1. A review of the test results did not reveal any unusual discrepancies about the rubber material, even though the material requirements specified for epichlorohydrin rubber were not known at this time and the rubber gasket sample was in contact with water and fuel in the IPDS out in the field at Fort Lee.

Table 1. Properties of the Epichlorohydrin Rubber Material in IPDS Coupling Gasket Samples

Properties	
Original	
Tensile Strength	1,747 psi
100% Modulus	817 psi
Elongation	437 %
Hardness	53
Bashore, Rebound	32%
Die C Tear, at RT, lb/in	197 lb/in
Heat Resistance, 70 hr Aging	
At 212° F Tensile Retained	90%
At 212° F 200% Modulus Retained	81%
At 250° F Tensile Retained	112%
At 250° F 200% Modulus Retained	62%
At 250° F Elongation Retained	79%
At 212° F Die C Tear Retained	117%
At 250° F Die C Tear Retained	120%
Compression Set, % (46 hr)	
At 212°	27°
At 250°	48°

A simple accelerated corrosion test procedure was established to verify the mode of corrosion of the bare aluminum surface by the rubber gasket material. The test was set up to simulate corrosion of the aluminum by a rubber gasket under compression in a moist or wet environment. In this case, a small specimen was cut from the IPDS rubber gasket sample and sandwiched between two small bare aluminum pipe grooved end pieces. The bare surfaces of the aluminum pieces were in contact with the rubber specimen. All three pieces were clamped together in a stainless steel clamp to simulate the coupling in the clamped position at the pipe joint (see Figures 3 and 4). The clamped test specimens were placed inside an oven that was set at 160° F and 90% humidity (deionized water supply). They were left in the oven for 2 weeks.

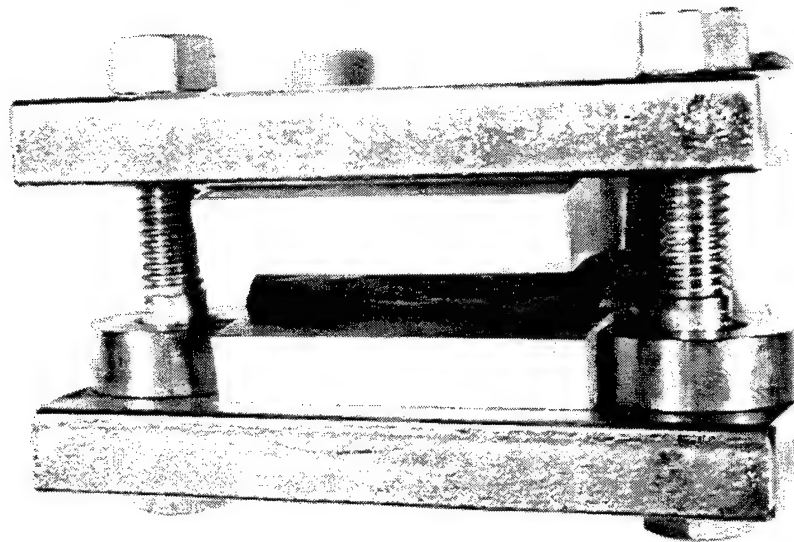


Figure 3. View of the cross-sectional rubber specimen placed between two small, curved aluminum pipe pieces in the stainless steel clamp for the accelerated corrosion test (actual size). This setup would simulate the rubber gasket in compression inside the IPDS snap-joint coupling in the clamped position. The compressed seal lips of the gasket is in contact with the bare surface of the curved IPDS pipe pieces.

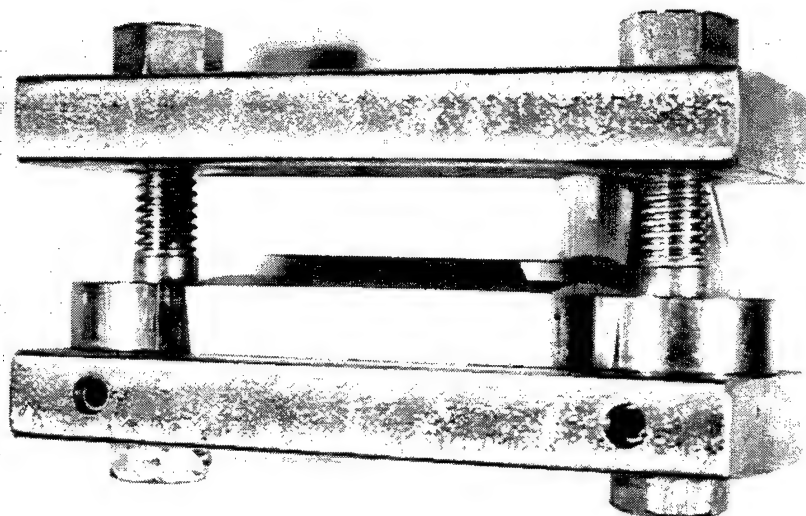


Figure 4. View of the flat rubber specimen placed between two small, curved aluminum pipe pieces in the stainless steel clamp for the accelerated corrosion test (actual size). The specimen is in contact with both bare aluminum surfaces.

The first corrosion tests were performed on two rubber specimens cut from a used IPDS epichlorohydrin rubber half sample from Fort Lee. One of them had its original surface left on, and the other specimen had its outer skin sliced off to expose new surfaces. Figure 5 shows a typical example of the corrosion on the bare aluminum surfaces after the corrosion test. Significant amounts of chlorine and lead were detected by x-ray analysis in the white corrosion products formed on the machined surface of the aluminum piece. The mode of corrosion on the aluminum pieces was similar to the type of corrosion that was observed on the corroded aluminum pipe grooved end.

X-ray analysis was performed on two new one-piece IPDS rubber gasket samples made from two different rubber materials: reformulated epichlorohydrin and nitrile. The analysis revealed



Figure 5. View of corroded area on the bare metal surfaces in contact with the small rubber sample (middle) after the 2-week experimental accelerated corrosion test in the oven (160° F and 90% humidity) (slightly larger than actual size). The aluminum piece on the right has the original machined convex surface, which did have some corrosion, but not as extensive as seen in Figure 1.

slightly higher chlorine and lead contents and lower zinc content in the one-piece epichlorohydrin gasket than in the earlier two-piece gasket sample (two integral split halves). No chlorine was detected in the nitrile rubber gasket sample.

Small rubber specimens (see Figure 6) were cut from both new one-piece gasket samples for similar accelerated tests, as was done for the earlier two-piece gasket sample. The paint on the convex outside surface of the aluminum pipe piece was removed by grinding on a 60-grit sanding belt, producing a bare surface that will be in contact with the rubber specimen to simulate the original machined surface on the pipe grooved ends. The concave inside surface of the other pipe piece remained intact, but it also was in contact with the rubber specimen.

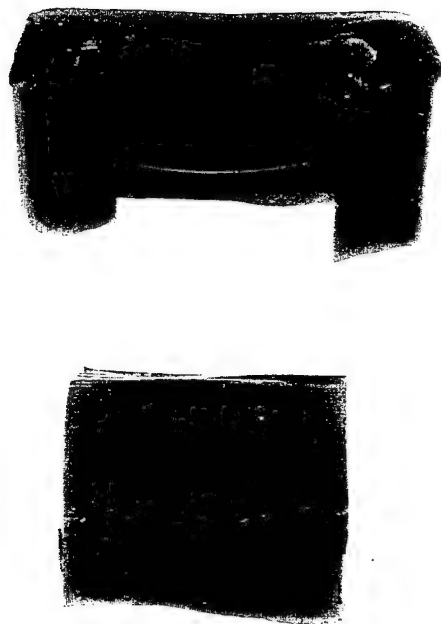


Figure 6. Small rubber specimens cut from the one-piece IPDS coupling rubber gasket samples for the accelerated corrosion tests (magnification:  $\times 1.4$ ). The top specimen is the cross section of the C-shaped rubber gasket showing the underside with a reinforcing rib. The bottom specimen is a flat rubber specimen with the seal lips cut off.

The results of the corrosion tests by two new one-piece gasket rubber specimens on the bare aluminum surfaces are shown in Figures 8–11. The type of the corrosion attack on the aluminum in contact with the reformulated epichlorohydrin rubber specimens was the same that was observed on the bare aluminum pipe grooved ends in contact with the two-piece epichlorohydrin rubber gaskets inside the IPDS snap-joint couplings on the assembled IPDS unit in the field at Fort Lee. Significant amounts of chlorine and lead were detected by x-ray analysis in the white corrosion products formed on the bare aluminum surface in contact with the reformulated epichlorohydrin rubber specimen. This confirmed the conclusion made in the earlier corrosion investigation that chlorine, as one of the ingredients in the rubber material, played a part in the corrosion of aluminum. The extent of corrosion observed on corroded surfaces of the small aluminum pipe pieces in the corrosion test was also superficial with a few small, shallow surface

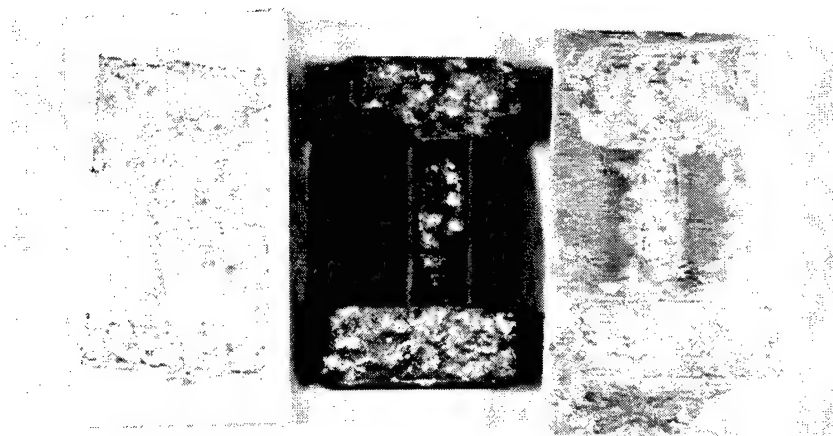


Figure 7. View of the corroded areas on the bare metal surfaces that were in contact with the reformulated epichlorohydrin rubber specimen (black) after the 2-week experimental accelerated corrosion test (actual size). The rubber specimen is shown with its underside and the reinforcing rib in the upright position. The concave bare surface of the left aluminum pipe piece was in contact with the top side of the rubber specimen, whereas the convex and bare ground surface of the right aluminum piece was in contact with the seal lips and the reinforcing rib on the underside of the rubber specimen. Note the corroded areas of the white corrosion products outlining the shape of the rubber specimen in direct contact with the bare surfaces of both aluminum pieces.

pittings. A noticeable volume buildup of corrosion products, which was formed on the aluminum surface, was observed.

No significant corrosion by nitrile rubber specimens on the bare aluminum surfaces was observed. However, the rubber specimens were stuck to the metal surface to the point that a thin layer of the rubber material was left behind when the specimens were pried off. This would

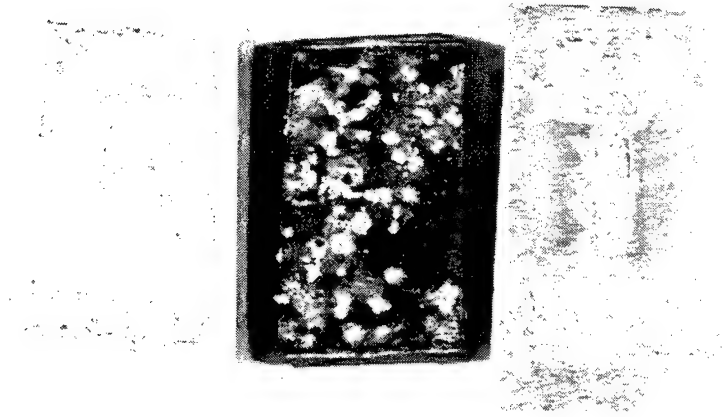


Figure 8. View of the corroded areas on the bare metal surfaces that were in contact with the reformulated epichlorohydrin rubber specimen (black) after the 2-week experimental accelerated corrosion test; except that the black rubber specimen was turned over to view the top side, which matches the outline of the corroded area on the bare surface of the left aluminum pipe piece (actual size).

indicate the need to apply a nonsticking coating on the bare aluminum surface before clamping the nitrile rubber gasket in place.

### 3. CONCLUSIONS

Based on the previous findings, it is concluded that chlorine in the epichlorohydrin rubber material used in the IPDS integral split rubber gaskets played an important part in the corrosion of aluminum. Chlorine, in the form of ions, combined with moisture or water to form hydrochloric acid, which, in turn, corroded the bare aluminum surface in contact with the epichlorohydrin rubber gasket inside the IPDS snap-joint coupling clamped around the pipe single-grooved ends.

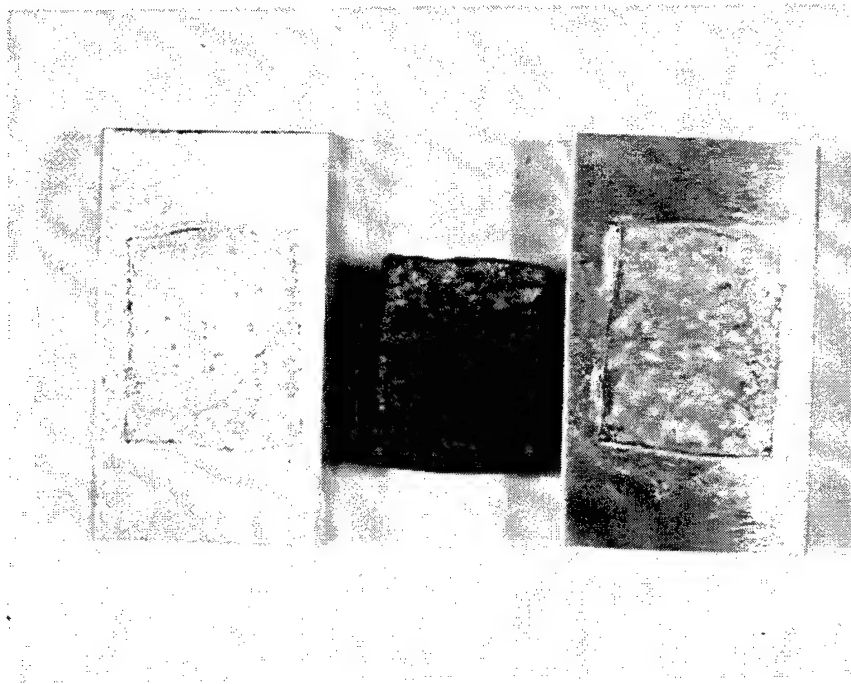


Figure 9. View of the corroded areas on the bare metal surfaces that were in contact with the flat reformulated epichlorohydrin rubber specimen (black) after the accelerated corrosion test (actual size). The concave surface is on the left aluminum pipe piece, and the convex surface is on the right piece. Note the corroded areas of the white corrosion products (gray areas) outlining the shape of the rubber specimen in direct contact with the bare surfaces of both aluminum pieces.

The extent of corrosion on the corroded pipe grooved ends was superficial with a few small, shallow surface pittings, but the volume buildup of the white corrosion products formed on the bare aluminum machined surface was apparently sufficient to affect the sealing of the rubber gaskets against the fuel leaks at the joint connections.

The accelerated corrosion test procedure established and used in this work was adequate to verify the mode of corrosion on the bare aluminum surface in contact with the rubber specimen and to quickly evaluate the corrosive effects of new gasket rubber materials on the bare aluminum surface under moist or wet environmental conditions. With this corrosion test, the reformulated



Figure 10. View of the aluminum surface areas in contact with the nitrile rubber specimen (black) after the accelerated corrosion test (actual size). The rubber specimen is shown with its underside and reinforcing rib in the upright position. The concave bare surface of the left aluminum pipe piece was in contact with the top side of the rubber specimen, whereas the convex and bare ground surface was in contact with the seal lips and the reinforcing rib on the underside of the rubber specimen. Note that the dark areas outlining the contact points of the rubber specimen on the bare surfaces of the aluminum pieces appeared to be a thin layer of rubber material bonded to the metal surface. The test specimen was actually stuck to the metal surface and had to be pried off by the fingers. No significant corrosion was observed on the metal surfaces in contact with the rubber specimen.

epichlorohydrin rubber with the high chlorine content corroded the aluminum in the same manner as had occurred on the corroded IPDS aluminum pipe grooved ends in the field at Fort Lee. No significant corrosion had occurred on the bare aluminum surface in contact with nitrile rubber material, which contained no chlorine; however, this rubber material may stick to the metal surface to the point that a thin layer of the rubber material may be left behind on the metal surface when the nitrile rubber gasket is removed.

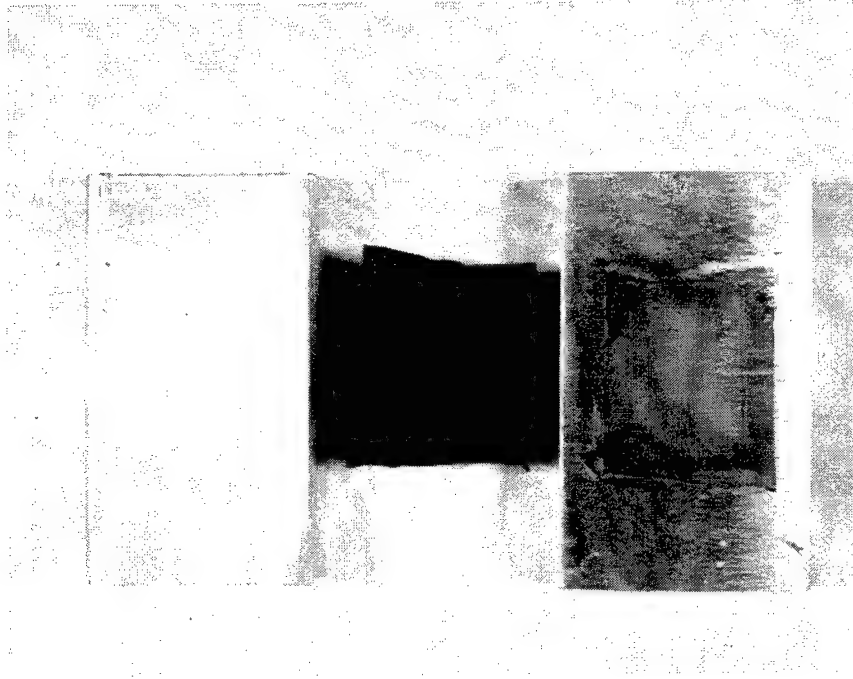


Figure 11. View of the aluminum surface areas in contact with the flat nitrile rubber specimen (black) after the accelerated corrosion test (actual size). The concave surface of the left aluminum pipe piece has no significant effect from being in contact with the rubber specimen. The dark area observed on the convex and ground surface of the right aluminum piece appeared to be a thin layer of the rubber material bonded to the metal surface, outlining the contact area of the rubber specimen on the metal surface. As mentioned in Figure 10, the specimen was actually stuck to the aluminum piece before it was pried off.

A rubber material with a high chlorine content, such as epichlorohydrin, should not be used in contact with aluminum. The rubber gaskets inside the IPDS joint couplings should be made of a suitable rubber material that does not contain chlorine and will meet other material and performance requirements specified for the IPDS gaskets, particularly at low temperatures.

#### 4. RECOMMENDATIONS

No rubber material containing chlorine should be used for the IPDS rubber gasket. The accelerated corrosion test that was established in this work may be used to quickly evaluate different rubber materials for potential use in the gasket to study their corrosive effects on the bare aluminum surface under moist or wet environmental conditions. In the event that the rubber material used for the gasket may stick to the aluminum, which happened with the nitrile rubber, a nonsticking coating may need to be applied on the bare metal surface of the pipe grooved ends before the IPDS snap-joint coupling is clamped on at the pipe joint.

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13. ABSTRACT (Maximum 200 words)  Because of fuel leaks at a number of mechanically connected joints, the Inland Petroleum Distribution System (IPDS) unit at Fort Lee, VA, was disassembled. Corrosion had occurred on the bare surfaces of the aluminum pipe single-grooved ends in the connection joints. These corroded surfaces were in contact with the rubber gaskets inside the IPDS joint couplings. An investigation was performed to determine the cause of the corrosion. The joint gasket was made of epichlorohydrin rubber material, which contains a high chlorine content. Some chlorine, in the form of ions, combined with water or moisture trapped in the joint gaps to form hydrochloric acid to corrode the aluminum. Therefore, the primary cause of corrosion on the bare aluminum surfaces was the improper use of epichlorohydrin rubber material for the gaskets inside the joint couplings. A simple accelerated corrosion test procedure was established to verify the mode of corrosion on the bare aluminum surfaces. Samples of the original IPDS rubber gaskets were taken, and new sample gaskets made of two different rubber materials (i.e., reformulated epichlorohydrin and nitrile) were evaluated on bare aluminum surfaces.				
14. SUBJECT TERMS failure analysis, epichlorohydrin rubber, chlorine, corrosion, aluminum pipe, mechanical joint coupling			15. NUMBER OF PAGES 24	
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